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The effect of scanning the palate and scan body position on the accuracy of complete-arch implant scans

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The Effect of Scanning the Palate and Scan Body Position on the Accuracy of Complete-Arch Implant Scans

Abbreviated title: The Accuracy of Complete-Arch Implant Scans

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Conflict of Interest Statement

No conflict of interest.

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Author Contribution Statement:

Ryan M. Mizumoto: Design, data collection

Gülce Alp: Data analysis, drafting article

Mutlu Ozcan: Design, Critical revision of article

Burak Yilmaz: Design, Data interpretation, Critical revision of the article, Approval of article

ABSTRACT

Background: Whether stitching the palate during intraoral digital scans of implants would improve scanning accuracy is unclear.

Purpose: Evaluate the effect of stitching the palate and the scan body position on the trueness (distance and angular deviation) and precision of digital scans in a completely edentulous situation.

Materials and Methods: An edentulous maxillary model with 4 parallel dental implant analogs was fabricated and intraoral scan bodies were attached. The entire surface was scanned using an industrial scanner to generate a master reference model digital scan (MRM-DS). Digital scans of the master model were made using an intraoral scanner and the resulting scans were divided into 2 groups [stitched palate (S) and unstitched palate (U)]. All test scans were converted to STL files and superimposed over the MRM-DS.

Results: For trueness, scan body position had a significant effect on distance (*P*<.001) and angular (*P*<.001) deviation values. In terms of precision, no significant difference was found in distance (*P*=.051) and angular deviations (*P*=.36) between stitched and unstitched techniques.

Conclusions: The accuracy and precision of digital scans of edentulous maxillary arch was similar independent of stitching or unstitching the palate. Position of the implant had a significant effect on trueness.

Keywords: Scan body, Digital scans, Accuracy, Palate

INTRODUCTION

Implant impressions can be made conventionally or digitally using computer-aided design and computer-aided manufacturing (CAD-CAM) technologies.[1-5] Conventional impression techniques require several clinical and laboratory steps, which could introduce flaws.[3] The developments in digital technology give clinicians the option to digitally scan the structures.[4-6] While the accuracy of various implant impression techniques has been the subject of several studies and many techniques have been reported both in conventional and digital implant scans, there are conflicting reports regarding the superiority of the impression technique's accuracy.[1,2,5-7] Some studies reported that the accuracy of digital implant scans are comparable with conventional impressions.[2,5,8]

Digital workflows play an important role in implant dentistry through acquiring implant positions and displaying them in a virtual model.[9] Scan bodies have been developed to take digital implant scans by creating an accessible surface for optical acquisition and are readily detectable and can be matched with the corresponding digital implant library by the software.[10-13] Geometrical features on the scan bodies supply information about the implant orientation, angulation, and 3D spatial position within the dental arch.[12,13] Digital implant scans can be performed directly following a digital workflow using intraoral scan bodies (ISBs) attached to the implants and an intraoral scanner (IOS) to capture the topography of the ISBs and the surrounding oral structures.[12-19] Digital implant scanning techniques using direct digital workflow have been popular in recent years parallel with the development of various intraoral scanners (IOSs) and their reported advantages.[1,16-19] Nevertheless, the accuracy of intraoral digital implant scan is affected by several factors; the IOS system, software program associated with the digital scan system, different scan bodies, experience of the operator, angulation and position of the implant(s), and quadrant.[7,13,16-19] In the literature, few studies have investigated the accuracy of ISBs that represents the 3D spatial position of implants.[16-19]

The scanning of edentulous arches has some challenges due to the lack of teeth as fixed reference points and anatomical landmarks, and has inaccuracies depending of the scanner, software, mucosal morphology and denture borders.[18-22] To improve the ability of the intraoral scanner to capture the palatal area of edentulous maxillary arches, different tissue additives, adhesive radiopaque markers, different amounts of pressure-indicating paste (PIP), intraoral scanning spray, and resin markers made from composite resin were used.[21-24] To obtain a complete scan of edentulous maxillary arches and to allow the software to accurately stitch the scanned surfaces together, Goodacre et al[22] suggested a scanning pathway starting with the crest of the ridge, then extending to scan the palatal area, and finally capturing the buccal and labial vestibules. However, not stitching the entire palate may be beneficial scanning edentulous maxilla for fixed reconstructions, because obtaining a complete scan including the palate in one scan round is difficult and may limit the ability of the IOS to stitch the surfaces and multiple images together especially when the patient has mobile tissue and gag reflex or limited mouth opening.[20-22,25] Although there are studies that investigated the effects of number of implants, angulations, implant depths, connection types, digital and conventional impressions techniques on implant impression accuracy,[16-19,26] studies which assessed the effect of stitching the palate on the trueness and precision of complete-arch digital implant scans of completely edentulous situations are lacking. The verification of the accuracy of including or not including the palate in digital implant scan will be beneficial for clinicians to select the optimal procedure when scanning implants in completely edentulous situations. The purpose of this study was to evaluate the effect of stitching the palate and the scan body position on the accuracy (trueness and precision) of digital implant scans when 4 implants are used in a completely edentulous maxilla. Distance deviation and angular deviations of 2 different techniques and different implant positions were evaluated for the trueness. The first null hypothesis was that the trueness of the scan would not be affected whether the palate is completely scanned or not. The second null hypothesis was that the scan body position would not affect the trueness of the scan. The third null hypothesis was that the precision of the scans would not be affected by the inclusion of the palate in the scan.

MATERIALS AND METHODS

A polyurethane master cast simulating an edentulous maxilla with 4 parallel dental implant analogs (TSV 4.1, Zimmer Biomet Dental, Winterthur, Switzerland) in the first molar and canine positions and a soft tissue replica was fabricated. Implant analogs were placed 3 mm below the maxillary model's surface and approximate distances were 20 and 14 mm between 2 anterior implants and anterior and posterior implants, respectively. An ISB was [DE (Dess-USA Dental Smart Solutions, Granite Bay, CA, USA)] attached to each dental implant analog and torqued according to the manufacturer recommendations.

A powder was sprayed to the entire model surface and the model was scanned using an ISO17025 calibrated structured blue light industrial scanner (COMET L3D, Carl Zeiss Optotechnik GmbH, Neubeuern, Germany), digitized and saved as a stereolithography (STL) file to generate a master reference model digital scan (MRM-DS). This industrial scanner's uncertainty was reported to be less than 11 µm (www.3d-engineering.net).

Digital scans of the master model[27] (Trios, 3Shape, Copenhagen, Germany) had a standardized path for all scans starting from the occlusal surface followed by the buccal and the palatal surfaces according to manufacturer's recommendation, by the same operator (R.M.M), and in the standardized temperature and humidity conditions. Two major criteria were taken in consideration when scanning: the condition of entirely scanned scan body surfaces and the absence of major holes. The resulting scans were divided into 2 groups with 7 scans each, those with a stitched palate (S) and those with an unstitched palate (U). A stitched palate was defined as a scan completed without any visible mismatch in the point clouds on the reconstructed image. An unstitched palate was defined as any 3D reconstruction that did not visibly merge together on the digital preview. All test scans were then converted to STL files to generate the study models. Then, test STL data from models was superimposed over the MRM-DS using an industrial metrology software (Polyworks, Innovemetric Software Inc., Quebec, QC, Canada) with a best-fit algorithm. When superimposing, the scan bodies were excluded and only unchanged surfaces in the STLs, ridges and model base, were used to minimize any alignment errors or averaging of data in the measured portion of the scan bodies. A coordinate system was created and used throughout the entire inspection. The scan body positions were labeled 1 through 4 according to implant positions [P1: implant at maxillary right first molar, P2: implant at maxillary right canine, P3: implant at maxillary left canine, P4: implant at maxillary left first molar]. All implant positions were evaluated in each inspection to determine the trueness with the 3D distance deviation and angular deviation of the scan bodies. The amount of distance and angular deviation between the corresponding scan bodies in the experimental scan and the MRM-DS was used to define trueness. The inverse of trueness was established both as the distance of the top of the scan body from the master scan to the experimental scan, and as the angular deviation of the scan body from the master to the experimental scan. The mean distance deviation and angular deviation of the scan bodies were also calculated for each technique.

Fifty-six measurements were made for distance and angular deviation comparisons. For the positional deviations, changes were evaluated in X, Y, and Z directions. The center points of scan bodies were located and a cross section was created 2.25 mm from the top of each scan body which was compared with the corresponding points on the MRM-DS. The distance formula was used to generate the 3D distance deviation. The raw data was entered into the distance formula and calculation was performed for each implant position separately. The same software was used to measure the angular deviation. The cylinders were fit to each scan body and a central axis was generated for each. Then, the nominal axis from the MRM-DS was referred to be at an angle of zero, and the final 3D angle between the superimposed MRM-DS and study model was recorded for each implant position separately.

Means and 95% confidence limits for distance deviation and angular deviation values for each combination of position and techniques studied were obtained. Each deviation data set was analyzed using a 2-way analysis of variance (ANOVA) using the restricted maximum likelihood estimation with the main effects being Technique and Position and with the interaction included in the statistical model (PROC MIXED, SAS Proprietary Software 9.3; SAS Institute Inc., Cary NC, USA). For an effect found statistically significant, a Tukey test was used to completely resolve the significance of pairwise comparisons. The degree of variance within groups of scans was used for precision, and the homogeneity of the variances between techniques was evaluated using 4 tests (Levene, O'Brien, Brown and Forsythe, and Bartlett). The variances of the deviations at each position within each technique were used to describe the inverse of precision. The variances were compared by a student's t-test for differences in variance between the techniques ($\alpha = 0.05$).

RESULTS

The results of the ANOVAs for distance and angular deviations are shown in Table 1,2 and 3. Means and 95% confidence limits for distance deviation and angular deviation for each combination of position and techniques studied are presented in Fig. 1, Fig. 2, Table 4, and Table 5.

For trueness, only position (*P*<.001) had a significant effect on distance deviation values, however, technique was not significant for distance deviation (*P*=.34). No significant interaction was found between technique and position (*P*=.74). For distance deviations, significant differences were found between different positions (*P*<.001) except between P1 and P2 (*P*=.59) and between P3 and P4 (*P*=.50). According to the Tukey adjustment, P3 and P4 had significantly higher distance deviation than P1 and P2 (*P*<.001). No statistically significant difference was found in the means of the distance deviations between stitched (142.7±41.41 µm) and unstitched techniques (160.3±21.5 µm). (*P*=.14).

The position (*P*<.001) had a significant effect on angular deviation, however, technique was not significant for angular deviation (*P*=.07). No significant interaction was found between technique and position (*P*=.99). Significant differences were found between different positions (*P*<.02) except for between P2 and P3 (*P*=.99). According to the Tukey adjustment, P4 had significantly highest angular deviation (*P*<.001) and P1 had the significantly lowest angular deviation (*P*<.02). No statistically significant difference was found for angular deviations between stitched and unstitched techniques (*P*=.94). The means in stitched technique was 0.41±0.1 degrees and in unstitched technique was 0.52±0.1 degrees. In terms of precision (Table 3), no significant difference was found in distance deviation (F=15.20, *P*=.051) and angular deviation (F=3.20, *P*=.36) between stitched and unstitched techniques.

DISCUSSION

This study evaluated the accuracy of digital implant scans using one IOS system in combination with 2 different scanning techniques (stitching or unstitching the palate). To the best of the authors' knowledge, this is the first study to analyze the effect of scanning technique in terms of inclusion of the palate, on the accuracy of digital scans of multiple implants using an intraoral scanner. The first null hypotheses that the trueness of the scan would not be affected by stitching the palate was accepted as palate's inclusion did not make a difference in trueness (3D distance deviation and angular deviation). The second null hypothesis that the scan body position would not affect the scan trueness was rejected because the scan body position had a significant effect both on distance and angular deviations. Significant differences in trueness with regards to distance deviation were found between different scan body positions in cross arches (P1-P3, P1-P4, P2-P3, P2-P4; $P<.001$) independent of anterior or posterior scan body positions. This might be due the curvature of maxillary arch.[16-19] P1 and P2 positions had significantly lower ($P<.001$) distance deviations than P3 and P4, whereas no significant difference was found between these pairs ($P=.50$). P4 had the highest ($P<.001$) and P1 had the lowest ($P<.02$) angular deviations. In terms of angular deviation, no significant difference was found between 2 anterior scan body positions (P2-P3; $P=.99$). This might be due to the linear scanning path at the anterior arch where these 2 implants were positioned.[16-19] During the scans of multiple implants, it may be challenging for the IOS to differentiate identical ISBs and to identify their location.[10] The IOS can interpret different scan bodies as only one and may paste images on top of each other.[28] The difference in the trueness of the scans at different implant positions in the present study might be due to the presence of identical ISBs at different positions.

The third null hypothesis was accepted as no significant difference was found in distance

(F=15.20, *P*=.051) and angular deviations (F=3.20, *P*=.36) between stitched and unstitched techniques. Precision of distance deviation was higher in stitched technique than the unstitched technique. However, this should be interpreted carefully as the *P* value of these techniques was slightly above .05 (*P*=.051). It has been reported that virtual surface reconstruction may be obtained more accurately when more point cloud density is obtained.[29] Accordingly, the slightly higher precision with stitched technique may be due to the increased point cloud density. Vandeweghe et al[30] evaluated the accuracy of 4 different IOSs for digital scans of 6 external hexagon implants in edentulous mandible and reported lower mean precision results than the present study with Trios scanner (3 Shape, Copenhagen, Germany). In the present study, implants had an internal hexagon connection. Imburgia et al[31] evaluated the trueness and precision of 4 different IOSs in 3 implant-supported partially edentulous and 6-implant-supported edentulous maxilla. In the edentulous model, the precision and the trueness with Trios3 scanner (3 Shape, Copenhagen, Germany) was also lower both in stitched and unstitched tecniques' trueness and precision results of the present study. The difference between these studies and present study results may be due to different number of implants, implant brands associated and different ISBs. Iturrate et al[32] evaluated the accuracy of digital scans of edentulous maxilla containing 4 cylinders to simulate 4 scan bodies. They evaluated accuracy with or without the use of an auxiliary geometric device (AGD) with 3 different IOSs and independent of IOSs they reported lower precision and trueness values than the present study when AGD did not use. The difference between this study and present study also might be due to the different ISBs.

Acquiring reliable digital scans with edentulous patients is challenging because the scanned surface may lack reference points between point clouds that may lead to improperly stitching of the images.[17,22,33] In the situation where the reference points lack, the images are stitched with compounding errors including inaccurate and noisy mesh or key parts of the scan can be identified as redundant points and cut out by the postprocessing algorithm. [17,22,32,33] The surface properties of the scanned area are also important factors that can affect point cloud density.[34] The patients have various hard and soft tissue textures with different reflective surfaces, have variations along the dental arch and anatomic irregularities are absent in the edentulous area to be scanned.[21,22] Shiny, rough, undercut, sharp surfaces are known to scan difficult and the saliva is known to create reflective surfaces.[16,35] Additionally, the areas between implants in edentulous arches are large and homogeneous that is difficult to scan accurately.[28,32] Gimenez et al also reported that reference points might lack for correct image stitching in flat mucosal surfaces when combined with a larger inter-implant distance.[36] Intraoral scanning, especially for posterior areas of arch, may be more difficult because of the lack of space. The camera tip must be rotated to capture scanning surfaces properly and the number of repetitions of images generally increases.[19] Digital scans of large spans and areas inevitably requires a larger amount of stitching images, thereby making the scanning more prone to errors.[18,19] However, in the present study the means of the distance (P=.14) and angular deviations (P=.94) were not significantly different between stitched and unstitched techniques. Independent of the scanning technique, distance deviations obtained in the present study were (142.7-160.3 μm) within the range that was reported in previous studies (47-226 μm) for complete-arch implant scans.[28,31] Although it was not possible to directly compare the present study results with other studies due to different digitization and evaluation methods used, present study results suggest that either palate stitching or unstitching may be used for digital scans of edentulous maxillary arches with 4 implants in tested positions. However, the accuracy of definitive frameworks fabricated through these scans should be studied for routine use of these techniques.

Distance and angular deviation results for trueness of implant positions in this study verified the findings of published studies, which reported that implant position could affect scan accuracy.[18,19,36] Papaspyridakos et al[37] evaluated the accuracy of casts of 6-implant-supported fixed complete prosthesis fabricated from splinted or non-splinted conventional impressions. They optically scanned the casts and reported that the position of the implants affected the 3D accuracy dependent of the splinted or non-splinted techniques which might be due to the curvature of the arch and the greater antero-posterior spread (P<.05). In contrast, in the present study, there was no significant interaction between implant position and technique in terms of both distance deviation (P=.74) and angular deviation (P=.99). The difference in the present study and the study by Papaspyridakos et al[37] might be due to different impression techniques and scanning technologies, and the absence of laboratory procedures in current study.

Gimenez et al reported digital scan accuracy based on parallel confocal laser (iTero; Cadent, software version 4.5.0.151),[19] active triangulation (CEREC AC Bluecam; Sirona, CEREC 4.0 software),[36] active wavefront sampling (True Definition; 3M ESPE)[18] and confocal microscopy[17] (2 different scanners: 3D Progress IO Scan; MHT and ZFX Intrascan; Zimmer Dental) technologies for the digital scans of 6 implants in maxillary models simulating different clinical conditions. According to their results, with active triangulation technology,[36] parallel confocal laser technology,[19] and active wavefront sampling technology,[18] the scanned distance affected the predictability of the accuracy of the IOS. The accuracy of first scanned quadrant was higher than the second quadrant. The accuracy of digital scans decreased with the increased length of the scanned part and the error increased with the increase in overlapping images with larger scanning areas.[18,19,36] In contrast, in the present study, distance deviations were significantly higher for scan bodies on the left side (P3, P4) where scanning started, and the highest angular deviation was seen in the first scanned implant (P4). The scanner used in the present study works with the principle of confocal microscopy to generate digital point cloud surfaces,[17] which is different from other referenced studies.

According to the results of a study by Gimenez et al,[17] with confocal microscopy technologies which use 2 different postprocessing correction modules of software programs, conflicting results were obtained associated with the difference in the method of algorithm correction. In contrast with the present study, the error increased from the first to the last scanned implant and the first scanned quadrant presented improved accuracy (P=.001) with 3D Progress intraoral scanner. Whereas, in line with the present study, last scanned quadrant presented improved accuracy with ZFX Intrascan (P=.002). Therefore, the difference of the results found in present study and these previous study results might be due to the differences in scanning technologies, the method of algorithm correction, and different scanning protocols applied.

Some IOSs use the first image as a reference and the subsequent images are stitched to the previous image with a best-fit algorithm to obtain the best possible overlap of both images. The error may increase with every stitching image because each overlap has its inherent error. Hence, it was reported to anticipate that the greater length of the distance, and the more stitching processes done, the larger the error could be seen.[17,19] Additionally, the scanner has to follow anterior area of the arch after scanning the first quadrant, which has been reported to result in remarkably increased distance deviation first to the second quadrant.[17-19,27] Imburgia et al[31] reported that scanning complete edentulous situations had less accuracy and are more difficult than scanning limited areas. Supporting this, in a previous study, a decrease in accuracy was reported to be expected over the length of the scanned arch due to the accumulation of registration errors.[38] However, in the present study, as the scanner wand moved and captured more information, the scan trueness improved for distance deviation. Additionally, in previous studies, different accuracies were obtained with different IOSs.[17,19] Vandeweghe et al[30] reported that the 3M True Definition and Trios scanners presented higher accuracy than the Lava COS and Cerec Omnicam IOSs. In light of these, it can be interpreted that distance and angular deviations change depending on the IOS system, with the amount of the overlaps of the images and with the distance from the first scanned implant.

Because it has been reported that different IOSs provide different accuracies in digital impressions,[30] one type of IOS was used in the present study for standardization purposes. This scanner works with the principle of confocal microscopy to generate digital point cloud surfaces and its uncertainity can be as low as 4.5 µm.[27] This scanner was selected because it was reported to be one of the most accurate for complete arch scans.[30,31] Relating the findings of this study to clinical situation should be done carefully as oral environment may present with variations, including tissue undercuts, lack of space, saliva, gag reflex that may affect the results. [20-22,25] The experience of the operator was reported to affect the accuracy in previous studies.[19,36] In the present study, only one experienced operator performed the scans for standardization, and different operators may affect the results. Also, different results may be obtained with different ISBs ,because it was reported that ISBs in different geometry might affect the accuracy (3D position and angular deviation).[39] In vivo studies evaluating digital implant scanning techniques for completely edentulous arches are required.

CONCLUSION

Within the limitations of this in vitro study, the following conclusions can be drawn:

1. The accuracy (trueness and precision) of digital scans of edentulous maxillary arch with 4

implants when the palate was stitched compared to unstitched was similar.

2. Position of the implant had a significant effect on trueness (distance and angular deviations). Implant at maxillary left first molar position (P4-first scanned scan body in scan path) had higher distance and angular deviations than scan bodies on other implants.

3. Even though the precision of scans had a tendency to be different for distance deviation, overall, the precision of scans was found to be similar when the scans with stitched palate were compared to scans with unstitched palate.

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FIGURE LEGENDS

Figure 1. Means and 95% confidence intervals of distance deviations for scanning techniques and implant positions.

Figure 2. Means and 95% confidence intervals of angular deviations for scanning techniques and implant positions.

TABLES

Table 1. ANOVA results comparing interactions between technique and position on 3D distance deviation in terms of trueness

Property	Effect	Dfnum	Dfden	F-ratio	P-value
3D Distance Deviation (μm)	Technique	1	12	0.99	.34
	Position	3	36	32.65	<.001
	Technique × Position	3	36	0.41	.74

df, numerator degrees of freedom; denominator degrees of freedom, 20.

Table 2. ANOVA results comparing interactions between technique and position on angular deviation in terms of trueness

Property	Effect	Dfnum	Dfden	F-ratio	P-value
Angular Deviation (°)	Technique	1	12	4.1	.07
	Position	3	36	30.17	<.001
	Technique × Position	3	36	0.05	.99

df, numerator degrees of freedom; denominator degrees of freedom, 20.

Table 3. ANOVA results for 3D distance and angular deviation in terms of precision

Property	**Dfnum**	**Dfden**	**F-ratio**	**P-value**
3D Distance Deviation (µm)	3	3	15.20	.051
Angular Deviation (°)	3	3	3.2	.36

df, numerator degrees of freedom; denominator degrees of freedom, 20.

Table 4. Mean 3D distance deviation (µm) values in different technique and implant positions. Different uppercase letters denote significant differences for different implant positions (adjusted *P*<.001). SD, Standard deviation.

Implant Position	Technique	Mean± SD
P1	Stitched	114.57± 33.2^{A}
	Unstitched	120.94± 18.43^{A}
P2	Stitched	89.42± 28.12^{A}
	Unstitched	115.83± 38.3^{A}
P3	Stitched	170.51± 58.41^{B}
	Unstitched	198.0± 34.2^{B}
P4	Stitched	196.2± 71.3^{B}
	Unstitched	206.28± 37.54^{B}

Table 5. Mean angular deviation (°) values in different technique and implant positions.

Different uppercase letters denote significant differences for different implant positions (adjusted *P*≤.03). SD, Standard deviation.

Implant Position	Technique	Mean± SD
P1	Stitched	0.21 ± 0.12^{A}
	Unstitched	0.34 ± 0.18^{A}
P2	Stitched	0.36 ± 0.07^{B}
	Unstitched	0.48 ± 0.22^{B}
P3	Stitched	0.39 ± 0.14^{B}
	Unstitched	0.48 ± 0.09^{B}
P4	Stitched	0.68 ± 0.16^{C}
	Unstitched	0.78 ± 0.16^{C}

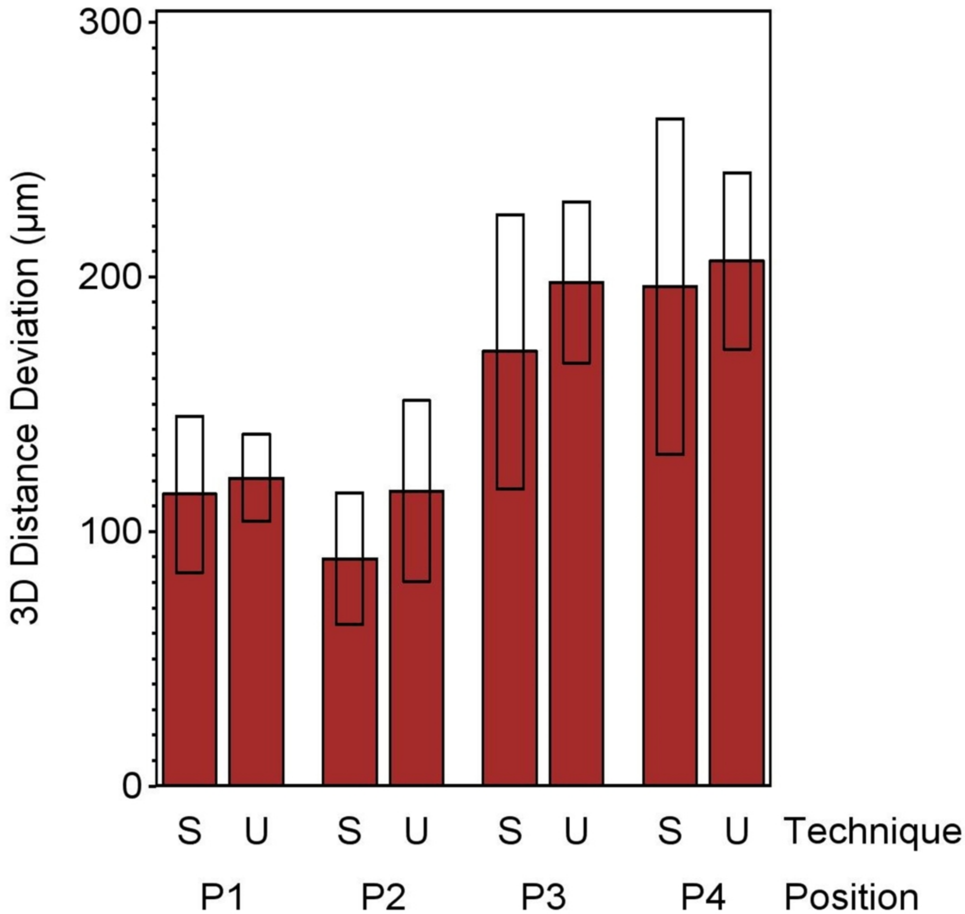

Figure 1. Means and 95% confidence intervals of distance deviations for scanning techniques and implant positions.

204x190mm (300 x 300 DPI)

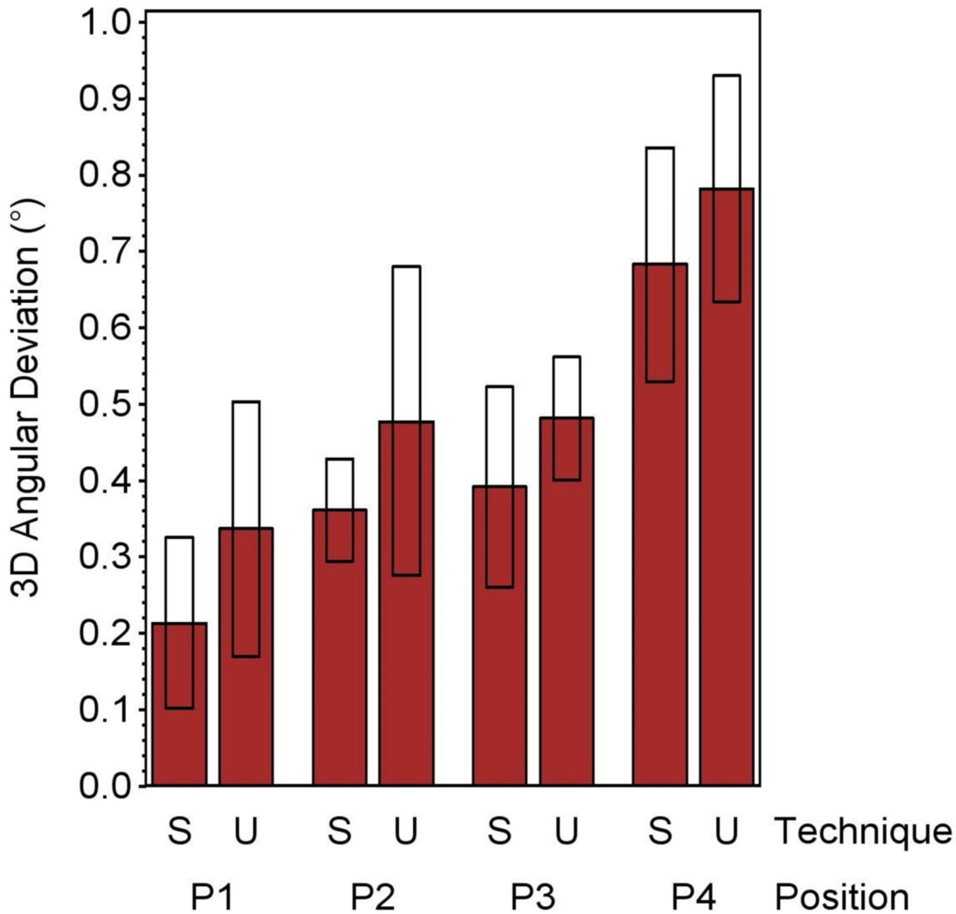

Figure 2. Means and 95% confidence intervals of angular deviations for scanning techniques and implant positions.

204x190mm (300 x 300 DPI)

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Table 1. ANOVA results comparing interactions between technique and position on 3D distance deviation in terms of trueness

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